

RECIPROCATING AND ROTARY MAGNETIC REFRIGERATION APPARATUS

FIELD OF THE INVENTION

The present invention relates to a magnetic refrigeration
5 apparatus and particularly to a reciprocating and rotary
magnetic refrigeration apparatus. The invention uses
reconfigured magnetocaloric material and a magnetization and
demagnetization mechanism. A Reciprocating and rotary
operation alternately magnetizes and demagnetizes the
10 magnetocaloric material. The device is coupled with a
design that includes a magnetic supply path and a heat transfer
unit to generate a thermomagnetic effect.

BACKGROUND OF THE INVENTION

Warburg first discovered the thermo-magnetic effect in
15 1881. Warburg found that by placing selected materials in a
magnetic field resulted in a temperature increase. Likewise,
removing selected materials from the magnetic field causes a
reduction in temperature. Thereafter a lot of effort has been
devoted to exploring possible applications for the interaction
20 of electromagnetic and thermal energy. Results of the
thermo-magnetic effect vary greatly depending on the method
of generating the magnetic field, selection of magnetocaloric
material and operating procedures. A magnetic refrigeration
apparatus is the most tangible application.

25 Reference found in U.S. Patent No. 4,916,907 in 1990 to

Munk et al, which discloses a magnetic inductor equipped with permanent magnets. However, it does not provide a complete and specific application for the magnetic refrigeration apparatus. U.S. Patent No. 6,526,759 discloses a design for the magnetic refrigeration apparatus. It mainly uses thermal piping coupled with the difference of thermal spots and adopts a rotating operation to complete thermal circulation. U.S. Patent No. 4,107,935 discloses a magnetic refrigerator that uses rotating magnetic material. It has a pump to deliver working fluid to a specially designed rotating thermo-magnetic apparatus. The thermo-magnetic apparatus contains magnetocaloric material and rotates continuously in one direction between a strong magnetic field and a weak magnetic field. The working fluid pumps through a complex flow path in the rotating thermo-magnetic apparatus to perform heat exchange with the magnetocaloric material for magnetic refrigeration.

Studies and research related to the thermo-magnetic effect show that magnetic field intensity and magnetic field control are areas that require more work. Permanent magnets are gradually replacing super-conducted material as the magnetic source and can simplify the design of low temperature operating environment. However, most permanently magnetic material used at present have a magnetic intensity of less than 1.5 Tesla. This is not adequate for most magnetic refrigeration

applications.

SUMMARY OF THE INVENTION

The primary object of the invention is to provide a reciprocating and rotary magnetic refrigeration apparatus that
5 magnetizes and demagnetizes magnetocaloric material reciprocally in a rotary fashion.

The embodiment according to the invention couples the concept of the rotary dynamo. The approach mainly focuses on generation of a magnetic path; rotary motion employed,
10 achieves this purpose. It includes deploying magnetocaloric material on the nose poles head of the stator coupled with magnetic supply coils. The magnetocaloric material magnetizes and demagnetizes by means of permanent magnets on a rotor and supplies current alternately to two adjacent
15 magnetic supply coils. Altering the temperature and entropy of the magnetocaloric material generates the thermo-magnetic effect. Through a heat transfer unit, heat exchanges between the magnetocaloric material and the atmosphere to achieve the cooling effect.

20 Another object of the invention is to provide a magnetic refrigeration apparatus that uses permanent magnets to enhance magnetic field intensity.

The apparatus according to the invention has permanent magnets deployed on the stator and rotor. Two adjacent
25 magnetic supply coils alternately receive current to generate

magnetic resistance and magnetic torque similar to the way a dynamo attracts a rotor to rotate reciprocally. Through the permanent magnets located on the stator and rotor, the magnetic path forms by the magnetic supply coils surrounding
5 the magnetocaloric material. Magnetization and demagnetization of the magnetocaloric material may help to increase magnetic field intensity.

The aforementioned, as well as additional objects, features and advantages of the invention will be more readily
10 apparent from the following detailed description, which proceeds with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a plane view of the present invention.

FIGS. 2A and 2B are schematic views of the present invention
15 in operating conditions. They show the rotating action during magnetization and demagnetization operations.

FIG. 3 is a cross section of the embodiment configuration of the heat transfer unit according to the present invention.

DETAILED DESCRIPTION OF THE PREFERRED 20 **EMBODIMENT**

Please refer to FIG. 1; the reciprocating and rotary magnetic refrigeration apparatus according to the invention includes:

a rotor 10 located in the center of the apparatus including a
25 permanent magnet 11 which has two magnetic poles N and S,

which rotate freely;

a stator 20 which is an annular element surrounding the rotor 10. The stator 20 also has a permanent magnet 21, which has two magnetic poles N and S;

5 Nose pole heads 1 - 8 are evenly spaced on the inner perimeter of the stator 20. Magnetocaloric materials 30 mount on the surface of each nose pole heads 1-8, respectively. Magnetic supply coils 40 surround the stator nose poles 1 - 8. Similar to the way a dynamo attracts a rotor to rotate
10 reciprocally. Current alternately feeds into any two adjoining magnetic supply coils 40 to generate magnetic resistance and magnetic torque. The permanent magnet 11 of the rotor 10 and the electromagnetic field of the magnetic supply coils 40 form a magnetic path to magnetize and
15 demagnetize the magnetocaloric material 30, thereby changing the temperature and entropy of the magnetocaloric material 30; and

a heat transfer unit including a first heat transfer tube 51 and a second heat transfer tube 52 that are in contact with the
20 magnetocaloric material 30. Through heat transfer of the first heat transfer tube 51 and second heat transfer tube 52, heat exchange between the magnetocaloric material 30 and ambience may be performed to achieve the cooling effect.

There are many materials desirable for use as magnetocaloric
25 materials 30, such as $\text{Dy}_3\text{Ga}_5\text{O}_{12}$, $\text{DyAl}_5\text{O}_{12}$, EuS , Tb-Gd ,

Er(NiCo)₂, and the like. The embodiment of the invention employs rare-earth metal Gd (gadolinium), first used to generate the thermo-magnetic effect using conventional techniques.

The permanent magnets 11 and 21 on the rotor 10 and stator 20
5 aim to boost the magnetic field intensity when the magnetocaloric material 30 is magnetized. In this embodiment, the permanent magnet 11 on the rotor 10 adopts a selected geometric shape such as a horseshoe shape. It has a dimension matching the location of the stator nose poles 1 - 8. When any two adjacent magnetic supply
10 coils 40 of the stator nose poles 1 - 8 alternately receive current, an electromagnetic field is generated creating magnetic resistance and magnetic torque similar to that of a dynamo; thus, attracting the permanent magnet 11 of the rotor 10, thereby driving the rotor 10 to rotate reciprocally. Through the
15 magnetic paths jointly formed by the permanent magnets 11 and 21 on the rotor 10 and stator 20 respectively, and the magnetic supply coils 40 surrounding the magnetocaloric material 30, the magnetocaloric material 30 magnetizes. The magnetic field intensity for magnetizing the magnetocaloric
20 material 30 increases.

In the embodiment shown in the drawings, the number of stator nose poles 1 - 8 is eight, and two permanent magnets 11 and 11' embedded in the rotor 10 each of which are formed in the shape of a horseshoe. Both of the permanent magnets 11 and 11' have two
25 permanent magnetic poles 12A and 12B, or 12A' and 12B'. Hence

there are in total, four permanent magnetic poles 12A, 12B, 12A' and 12B'. By designing the permanent magnet 11 in a desired geometric shape, the two permanent magnetic poles 12A and 12B of any permanent magnet 11 may face the two closest stator nose poles (such as stator nose poles 1 and 3) that are not adjacent to each other at the same time. Hence at any given time, the four permanent magnetic poles 12A, 12B, 12A' and 12B' of the two permanent magnets 11 and 11' are attracted to the electromagnetic fields generated by the magnetic supply coils 40 surrounding four stator nose poles (such as stator nose poles 1, 3, 5 and 7). As a result, magnetic paths are established and the magnetocaloric material 30 located on the head of the stator nose poles 1, 3, 5 and 7 are magnetized. According to this principle, an even number of total stator nose poles are used. The number of poles of the permanent magnets 11 embedded in the rotor 10 is one-half the number of the stator nose poles. For instance, in the event that there are three permanent magnets 11 embedded in the rotor 10 and six permanent magnetic poles, the number of the stator nose poles is eight. Other schemes may be set similarly.

In order to boost the flow of the magnetic path, the distal end of the stator nose poles 1 - 8 facing the permanent magnetic poles 12A, 12B, 12A' and 12B' of the permanent magnet 11 or 11' may be coupled with a flux concentrator 60. As shown in the drawings, the dimensions of the flux concentrator 60 are greater than the dimensions of the distal end of the stator nose poles 1 - 8, and are

substantially same as the dimensions of the permanent magnetic poles 12A, 12B, 12A' and 12B', thereby increasing magnetic induction capability.

Refer to FIGS. 2A and 2B for the reciprocal rotation of the rotor 10 to generate the thermo-magnetic effect and achieve the cooling function. In the condition shown in FIG. 2A, the permanent magnetic poles 12A, 12B, 12A' and 12B' of the permanent magnets 11 and 11' face respectively the stator nose poles 2, 4, 6 and 8. Meanwhile the magnetic supply coils 40 surrounding the stator nose poles 1, 3, 5 and 7 receive current (the magnetic supply coils 40 having current are marked in black, while the magnetic supply coils 40 with no current are marked in white) and generate an electromagnetic field. Therefore, the permanent magnets 11 and 11' rotate in the direction of the arrow (clockwise). The magnetocaloric material 30 is located on the head of the stator nose poles 1, 3, 5 and 7 magnetize, heat generation occurs and the temperatures rises.

In the condition shown in FIG. 2B, the magnetic supply coils 40 surrounding the stator nose poles 2, 4, 6 and 8 receive current and generate an electromagnetic field. The permanent magnets 11 and 11' rotate in the direction of the arrow (counterclockwise). The magnetocaloric material 30 located on the head of the stator nose poles 2, 4, 6 and 8 magnetize, heat generation occurs and the temperatures rises. By contrast, current supplied to the magnetic supply coils 40 surrounding the stator nose poles 1, 3, 5 and 7, stops.

As a result, the magnetocaloric material 30 located on the head of the stator nose poles 1, 3, 5 and 7 are demagnetized heat absorption effect occurs and the temperature drops.

Thus by means of magnetizing and demagnetizing the magnetocaloric material 30 located on the head of the stator nose poles (1, 3, 5, 7 or 2, 4, 6, 8), the magnetocaloric material 30 may produce heat and absorption effects. Heat exchange between the magnetocaloric material 30 and the atmosphere takes place through the first heat transfer tube 51 and the second heat transfer tube 52 that are in contact with the magnetocaloric material 30. This achieves the cooling effect.

The heat transfer unit aims at boosting heat exchange between the magnetocaloric material 30 and the atmosphere, hence the cooling effect. The first heat transfer tube 51 and the second heat transfer tube 52 are siphon type miniature tubes that have partial contact with the surface of the magnetocaloric material 30 on two sides of the stator nose poles 1 - 8 (as shown in FIG. 1). The rest of the tube sections extend to the atmosphere outside the reciprocating and rotary magnetic refrigeration apparatus. Through the heat transfer function of the first heat transfer tube 51, and the second heat transfer tube 52, heat exchanges between the magnetocaloric material 30 and the atmosphere.

Refer to FIG. 3 for an embodiment of the first heat transfer tube 51 and the second heat transfer tube 52. The heat transfer tubes alternate. A flow control valve 53 (such as a 4/2 way valve) is

provided to switch heat transfer flow. Namely, the first heat transfer tube 51 and the second heat transfer tube 52 respectively provide heat transfer function for the magnetocaloric material 30 on the head of any two adjacent stator nose poles (1,3, 5, 7 or 2, 4, 6, 8).

5 As shown in FIG. 1, the first heat transfer tube 51 provides the heat transfer function for the magnetocaloric material 30 on the head of the stator nose poles (1,3, 5, 7). The second heat transfer tube 52 provides the heat transfer function for the magnetocaloric material 30 on the stator nose poles (2, 4, 6, 8). The flow control

10 valve 53 has a first connection port 531 and a second connection port 532 on one side to connect respectively to the first heat transfer tube 51 and the second heat transfer tube 52. The flow control valve 53 has a third connection port 533 and a fourth connection port 534 on another side to connect respectively to a heat absorption device

15 54 and a heat discharge device 55. The heat absorption device 54 and heat discharge device 55 are also structures formed by siphon-type miniature tubes; however, their areas are greater than the first heat transfer tube 51 and the second heat transfer tube 52. The heat discharge device 55 aims to transfer heat flow (i.e.

20 discharge heat absorbed by the magnetocaloric material 30 to the atmosphere), while the heat absorption device 54 aims to transfer cold flow (i.e. absorb heat from the atmosphere and transfer it to the cooled magnetocaloric material 30 and thereby achieve cooling). Thus by means of the reciprocating rotary movement of the

25 reciprocating and rotary magnetic refrigeration apparatus, and

through switching the flow location with the flow control valve 53; heat generated by the magnetocaloric material 30 may be sent through the first heat transfer tube 51 and the second heat transfer tube 52 to the heat discharge device 55. On the other hand, when the magnetocaloric material 30 is cooling, ambient heat (such as the refrigeration box) absorbed by the heat absorption device 54 can discharge to the magnetocaloric material 30 of a lower temperature through the first heat transfer tube 51 and the second heat transfer tube 52 to perform the cooling function.

10 The working fluid contained in first heat transfer tube 51 and the second heat transfer tube 52 generally is a mixture of gas and liquid, but this is by no means the limitation. Gas, liquid, nitrogen or helium may also be used.

While the preferred embodiment of the invention has been set forth for the purpose of disclosure, modifications of the disclosed embodiment of the invention as well as other embodiments thereof may occur to those skilled in the art. Accordingly, the appended claims are intend to cover all embodiments that do not depart from the spirit and scope of the invention.

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